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DATA REDUCTION AND ANALYSIS FOR HEAVY PRIMARY COSMIC RAY EXPERIMENT IN EXPLORER VII SATELLITE

FINAL REPORT

Contract NASr-79
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C.

November 1, 1961 - December 31, 1963

UNPUBLISHED PRELIMINARY DATA

Principal Investigator: M. A. Pomerantz

Bartol Research Foundation
of
The Franklin Institute
Swarthmore, Pennsylvania

June 24, 1964

I. INTRODUCTION

The objective of the heavy nucleus experiment aboard Explorer VII was to determine the nature of the spectrum of primary cosmic rays with atomic number $Z \geq 6$ near solar maximum, and, in particular, to investigate intensity variations during the useful lifetime of the experiment. A description of the apparatus, as well as preliminary reports on some of the early results, are appended herewith, and hence will not be discussed in detail. The program conducted under the contract of which this constitutes the final report was directed toward a comprehensive analysis of the data after the completion of a rigorous and exhaustive data reduction process. Most of the results have already appeared in published papers which are included as part of the present report. Details which are not covered in the following sections may be found therein.

II. DATA REDUCTION PROGRAMS

The raw material upon which this work was based consisted of a set of punched cards containing scaled counts recorded during 15 second intervals as a function of real time. The satellite ephemeris was also available on magnetic tape. Initially, a program was written for amalgamating on a single tape the orbital information and the heavy nucleus data. From this tape, a set of cards (approximately 15,000) each containing the counts recorded in a single pass through a geographical box with 5° spread in latitude and 10° in longitude was punched. In addition to date, Universal Time, total recorded counts, total recording time, and position (latitude, longitude, altitude), the following information was entered on the cards: 1) geomagnetic cut-off rigidity based upon (a) the centered dipole approximation and (b) as calculated by Quenby and Wenk,[1)] 2) neutron monitor intensity at three ground-based stations -- Thule, Mount Norikura and Climax, 3) solar flare activity index, 4) Zurich relative sunspot number, 5) the geomagnetic planetary index, K_p, 6) the solar flux at 2800 MC as measured at Ottawa.

A. Altitude Correction of Geomagnetic Threshold Rigidity

The threshold rigidities computed by Quenby and Wenk were converted to the altitude of the satellite by means of the following relationship:

$$P_h = P_s \frac{(6370)^2}{(6370 + h)^2}$$

where P_s is the cut-off rigidity at the surface of the earth, and P_h is the cut-off rigidity at h km, the altitude of the satellite.

B. Correction of Threshold Rigidity for Omnidirectional Response of Detector

Since the ionization chamber has an essentially omnidirectional response, vertical cut-off rigidities must represent an appropriate average integrated over all possible directions of acceptance. Calculations relating to this problem were carried out, and a correction to the vertical threshold rigidity was determined and applied.

C. Rejection of Spurious Data

Although the detector was characterized by a high rejection ratio for trapped radiation, sufficiently high background counting rates render the data useless for the present purposes. A statistical procedure was established and programmed to reject data which did not satisfy the criteria adopted for assuring the absence of radiation belt effects.

III. PRIMARY HEAVY NUCLEUS ENERGY SPECTRUM

The energy spectrum during both quiet and disturbed periods was determined. Attempts were then made to find correlations between the spectrum and various indices of geophysical activity.

A. Quiet Period Spectrum

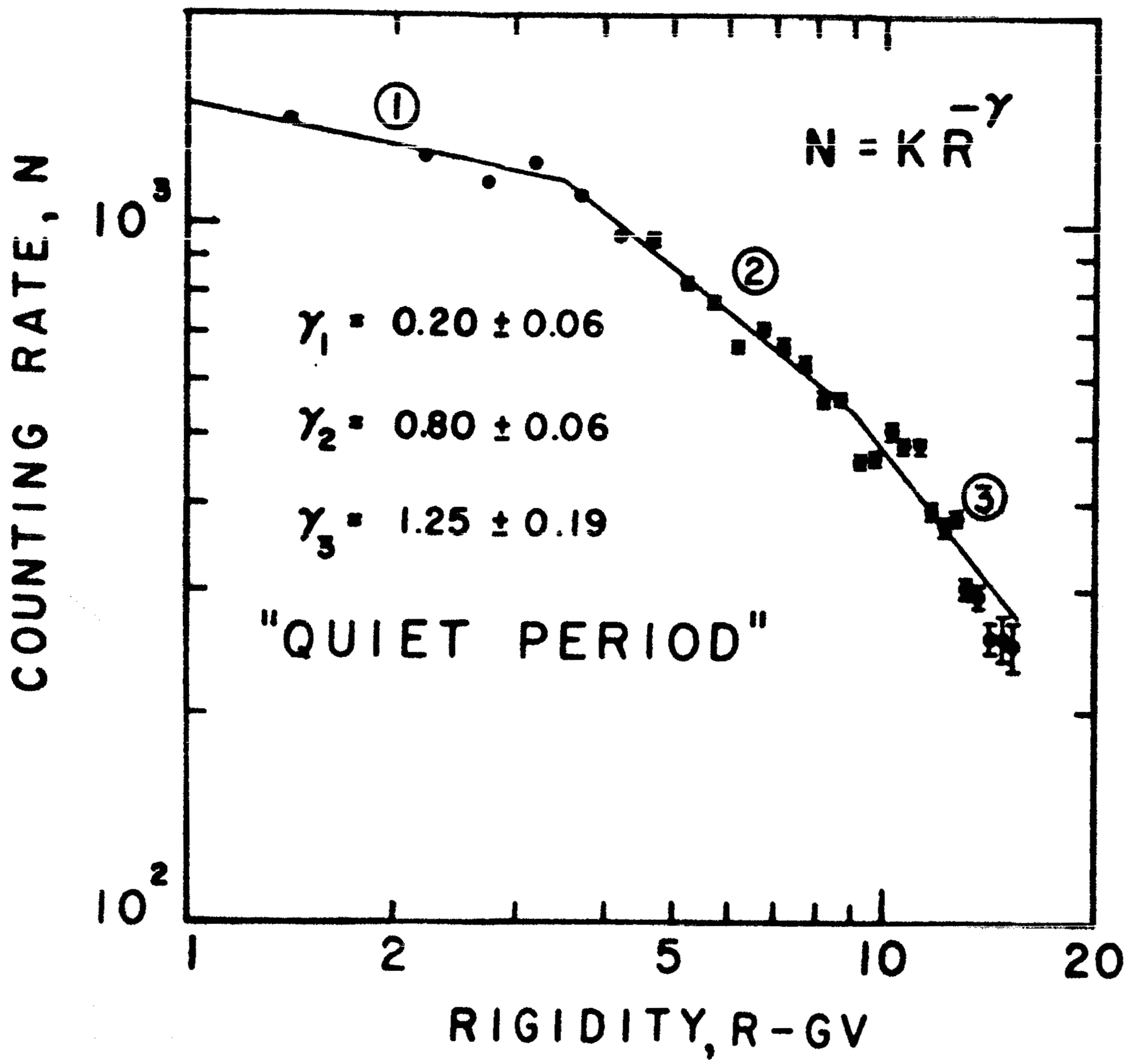
In order to provide a basis for the determination of the average spectrum characterizing solar maximum with the minimum statistical uncertainty attainable with the available data, a substantial quantity of data acquired during the so-called "quiet" period, characterized by the absence of Forbush-type decreases and large intensity fluctuations of the nucleonic component at sea level, was utilized. The seventy-six days comprising the quiet period actually consisted of two continuous intervals, one extending from 1 November to 2 December 1959, the other from 1 February to 15 March 1960. The spectrum was determined by sorting the cards for this period into 0.5 GV rigidity intervals. The average counting rate and statistical standard deviation, as well as the weighted average threshold rigidity, was then computed for each interval. The spectral parameters, and the associated statistical uncertainties based upon the dispersion of the points, were determined by machine computations of the best fit straight line according to the method of least squares.

Fig. 1 shows a plot of the quiet period data sorted in terms of threshold rigidities computed according to the formulation of Quenby and Wenk. The statistical uncertainties are indicated by the error bars whenever the standard deviation exceeds the size of the dots. If a single straight line is fitted to all of the points, the value of the exponent γ in the usual power law relationship $N = KR^{-\gamma}$ is 0.90 ± 0.04 for $4.0 < R < 15.5$ GV. However, it is clear from the figure that a single straight line does not adequately represent all the data. A minimum of three different exponents are required, as follows: 1) $\gamma = 0.20 \pm 0.06$, $1 < R < 3.5$; 2) $\gamma = 0.80 \pm 0.06$, $3.5 < R < 8.5$; 3) $\gamma = 1.25 \pm 0.19$, $8.5 < R < 15.5$.

A plot of the same data on a semilogarithmic scale is shown in Fig. 2. In this case, all of the points are satisfactorily represented by a single straight line in accordance with the relationship:

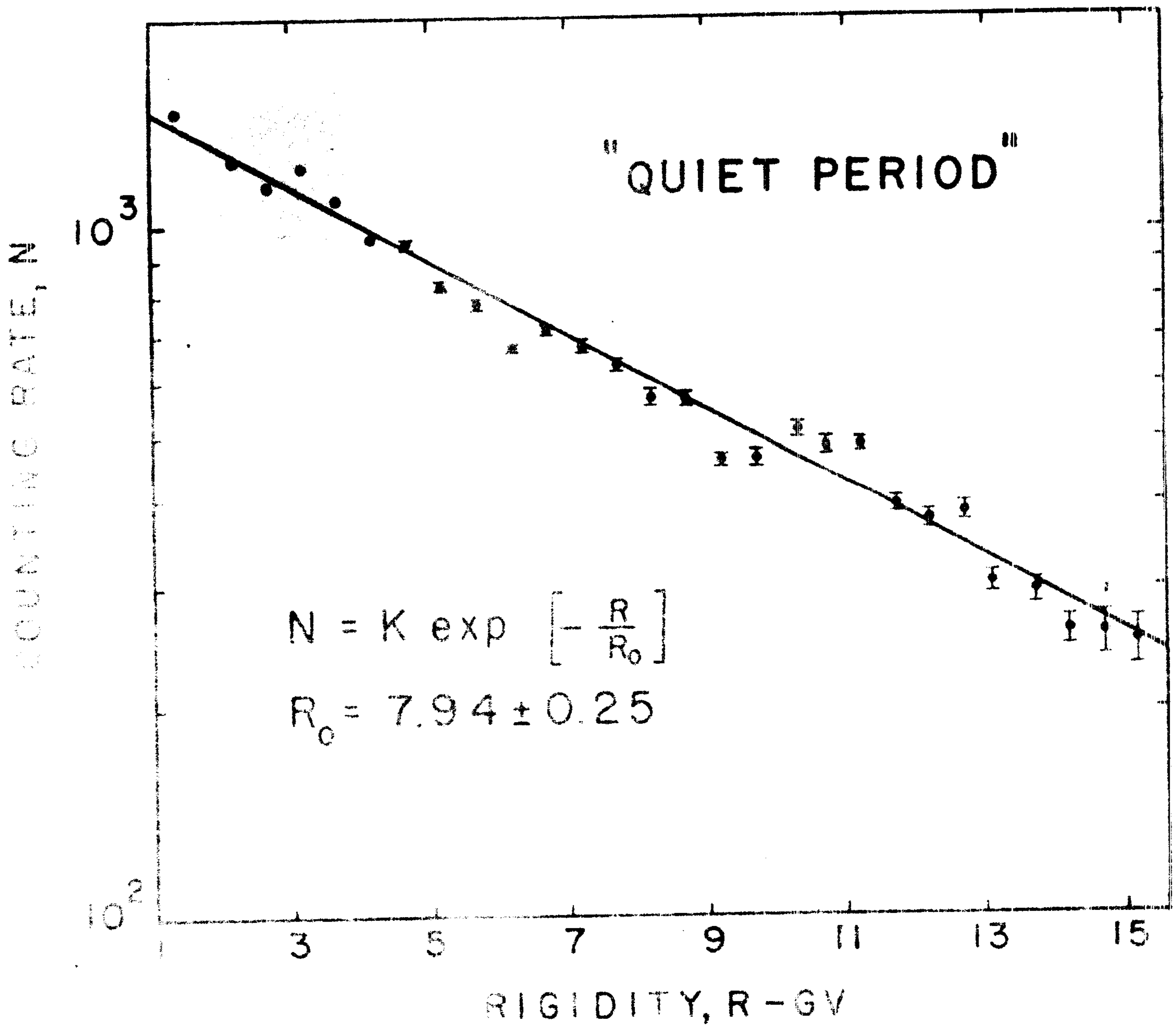
$$N(>R) = K \exp(-R/R_0), \text{ for } 1 < R < 15.5 \text{ GV}.$$

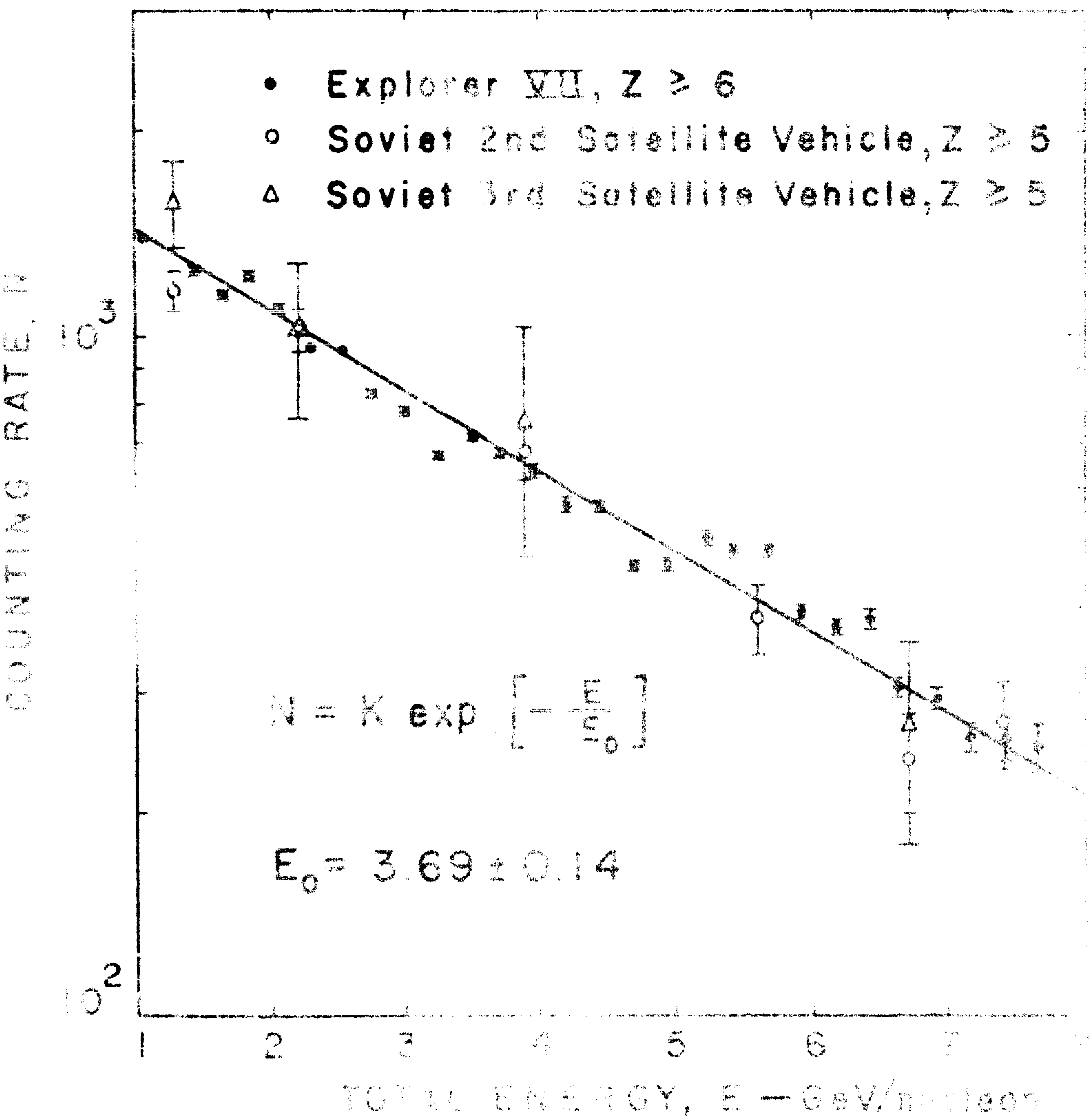
Furthermore, as is seen in Fig. 3, even if the spectrum is expressed in terms of total energy per nucleon, the exponential representation is applicable.



COUNTING RATE, N
10^3
10^2
1
2
5
10
20
RIGIDITY, R-GV
①
②
③
$N = KR^{-\gamma}$
γ_1 = 0.20 ± 0.06
γ_2 = 0.80 ± 0.06
γ_3 = 1.25 ± 0.19
"QUIET PERIOD"

Fig. 1


"QUIET PERIOD"
$N = K \exp\left[-\frac{R}{R_0}\right]$
$R_0 = 7.94 \pm 0.25$
COUNTING RATE, N
10^3
10^2
3
5
7
9
11
13
15
RIGIDITY, R - GV



Explorer VII, Z ≥ 6
Soviet 2nd Satellite Vehicle, Z ≥ 5
Soviet 3rd Satellite Vehicle, Z ≥ 5
COUNTING RATE, N
10^3
10^2
$N = K \exp\left[-\frac{E}{E_0}\right]$
$E_0 = 3.69 \pm 0.14$
1
2
3
4
5
6
7
TOTAL ENERGY, E — GeV/nucleon

The exponential relationship appears to apply regardless of how the time intervals are selected, and data recorded during periods of three or four days confirm this result. This characteristic has been utilized in various studies which would not otherwise have been feasible because of the ambiguity associated with the location of the breaks in the power law representation.

1. Dependence Upon Time

The data for the seventy-six days designated as the quiet period were divided chronologically into five groups, each representing a period of approximately two weeks. The exponential spectrum was then determined for each of these groups. As is seen in Table 1, there is no evidence for changes exceeding the statistical uncertainties in the values of K and R_0.

2. Dependence Upon Geomagnetic Activity

The data were sorted into three groups according to the value of K_p, the planetary index of geomagnetic activity. The mean values of K_p in the three groups were 1.5, 2.6, and 3.9. The maximum K_p value was 5.7. The values of K and R_0 corresponding to the three ranges of K_p are summarized in Table 2. Over the range of K_p covered by this analysis, no significant change is evident.

TABLE 1

Spectral parameters after chronological sorting.

2-week periods	K	R_0
1	1684 ± 69	8.62 ± .59
2	1631 ± 56	8.84 ± .51
3	1537 ± 61	8.16 ± .37
4	1581 ± 68	7.72 ± .43
5	1761 ± 48	7.57 ± .24

TABLE 2

Spectral parameters determined after K_p index sorting.

K Index	K	R_0
$K_p < 2$	1724 ± 74	7.72 ± 0.40
$2 < K_p < 3$	1686 ± 51	8.13 ± 0.33
$K_p > 3$	1686 ± 51	7.81 ± 0.31

3. Dependence Upon Neutron Monitor Intensity

The quiet period was defined in terms of the absence of large fluctuations, without respect to the level of the intensity of the nucleonic component. In order to determine whether the spectral parameters varied as a function of the nucleonic intensity, an intermediate latitude station, Mount Norikura, was selected as reference. The extreme variation of the intensity level amounted to only about 3%. Over this narrow range, as is seen in Table 3, no significant variation of either K or R_0 was revealed.

B. Spectrum During Disturbed Periods

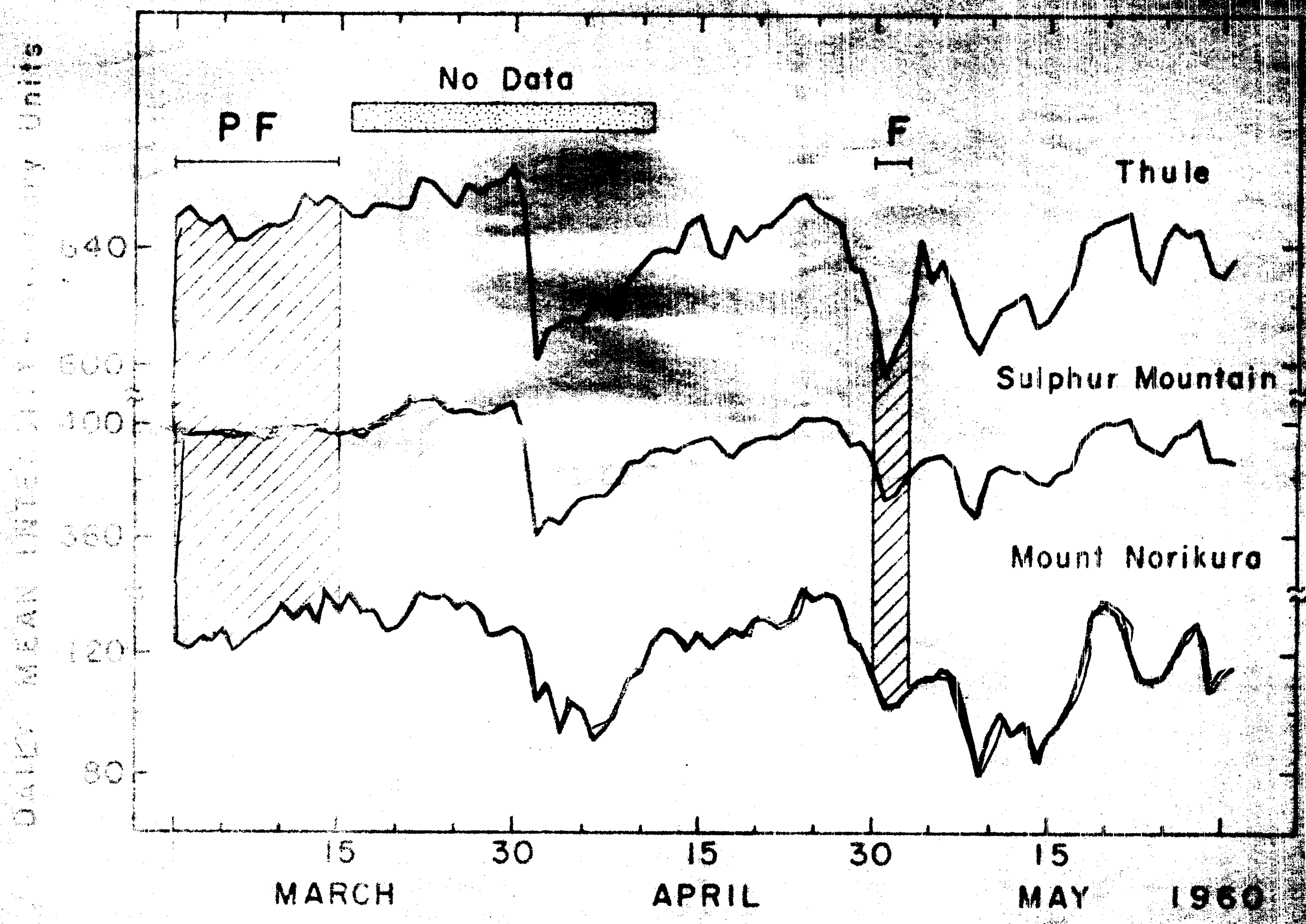
Several Forbush-type decreases occurred during the period for which data are available. Unfortunately, a malfunction of the on-board storage system coincided with the largest event, 31 March, 1960. Of the remaining events, only the one which commenced on 28 April, 1960, produced a statistically-significant change in the spectrum. Actually, this cosmic-ray storm started on 31 March, 1960, and, as is seen in Fig. 4, it was multiple in nature. The heavy nucleus spectrum was determined for the intervals PF and F indicated on the figure. The former represents the time prior to onset of the storm, whereas the latter corresponds to the lowest intensity level.

The exponential relationship during the decrease is shown in Fig. 5, whereas the spectra during PF and F are compared in Fig. 6.

TABLE 3

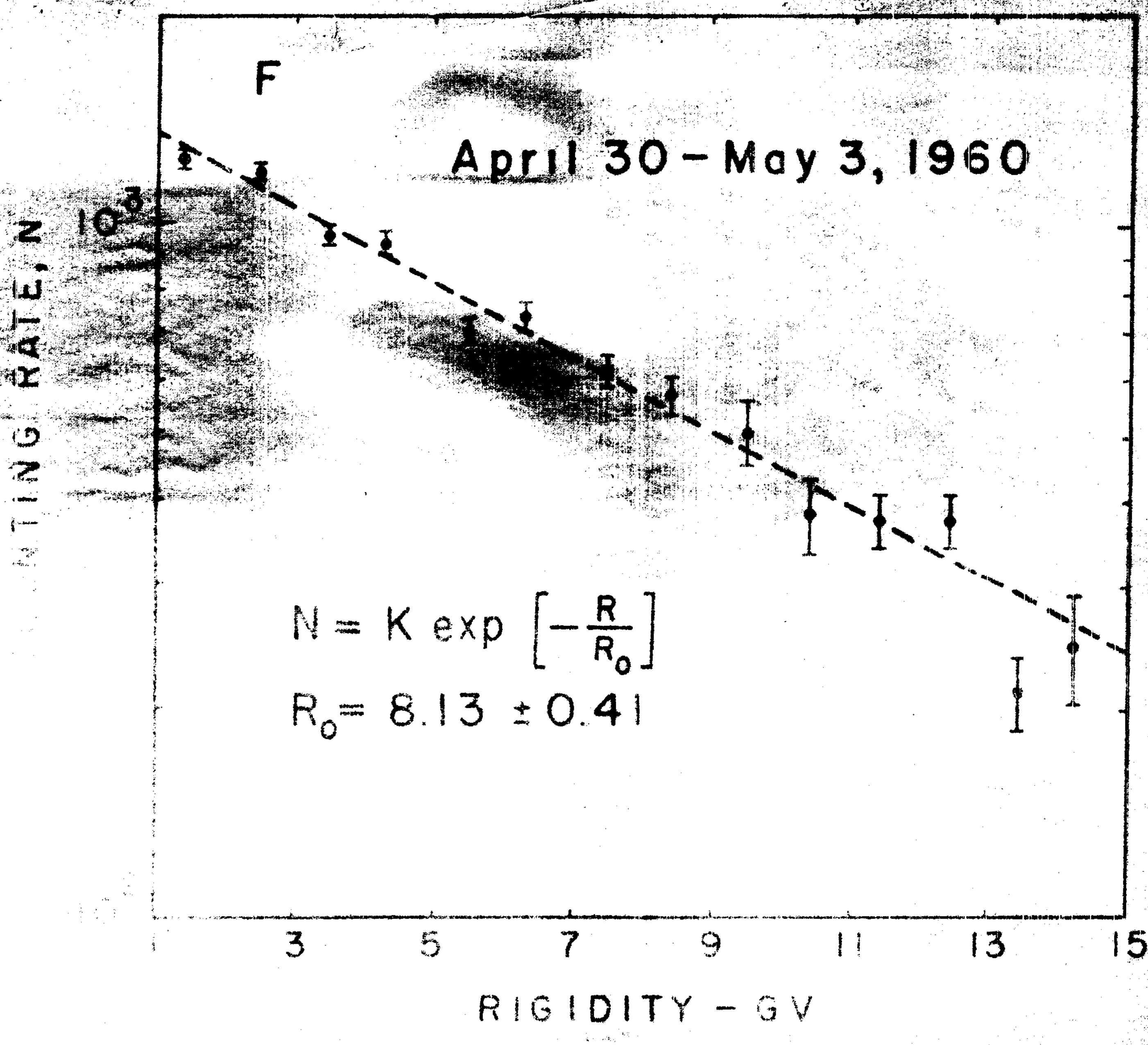
Spectral parameters determined after neutron monitor intensity sorting.

Intensity, %	K	R_0
11.1 - 12.3	1706 ± 47	7.62 ± .26
12.4 - 12.6	1739 ± 46	7.55 ± .27
12.7 - 13.2	1633 ± 43	8.32 ± .31
13.3 - 14.1	1686 ± 55	8.19 ± .37



No Data
PF
F
Thule
Sulphur Mountain
Mount Norikura
640
600
400
360
120
80
15
30
15
30
15
MARCH
APRIL
MAY
1960
Units

Fig. 4


F
April 30 - May 3, 1960
$N = K \exp\left[-\frac{R}{R_0}\right]$
$R_0 = 8.13 \pm 0.41$
10^3
TING RATE, N
3
5
7
9
11
13
15
RIGIDITY - GV

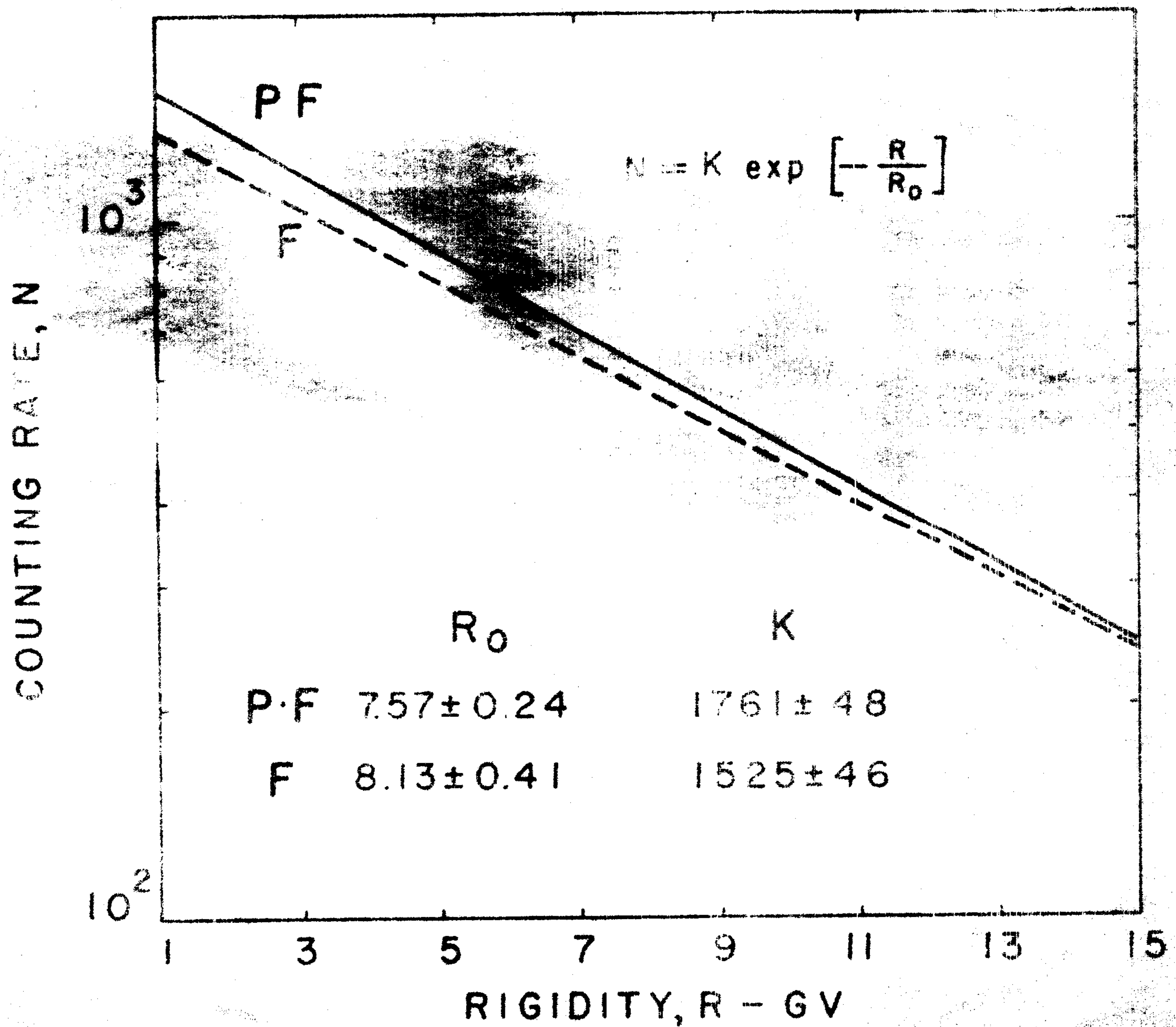

PF
F
$N = K \exp\left[-\frac{R}{R_o}\right]$
10^3
10^2
COUNTING RATE, N
R_o
K
P·F 7.57±0.24 1761±48
F 8.13±0.41 1525±46
1
3
5
7
9
11
13
15
RIGIDITY, R – GV

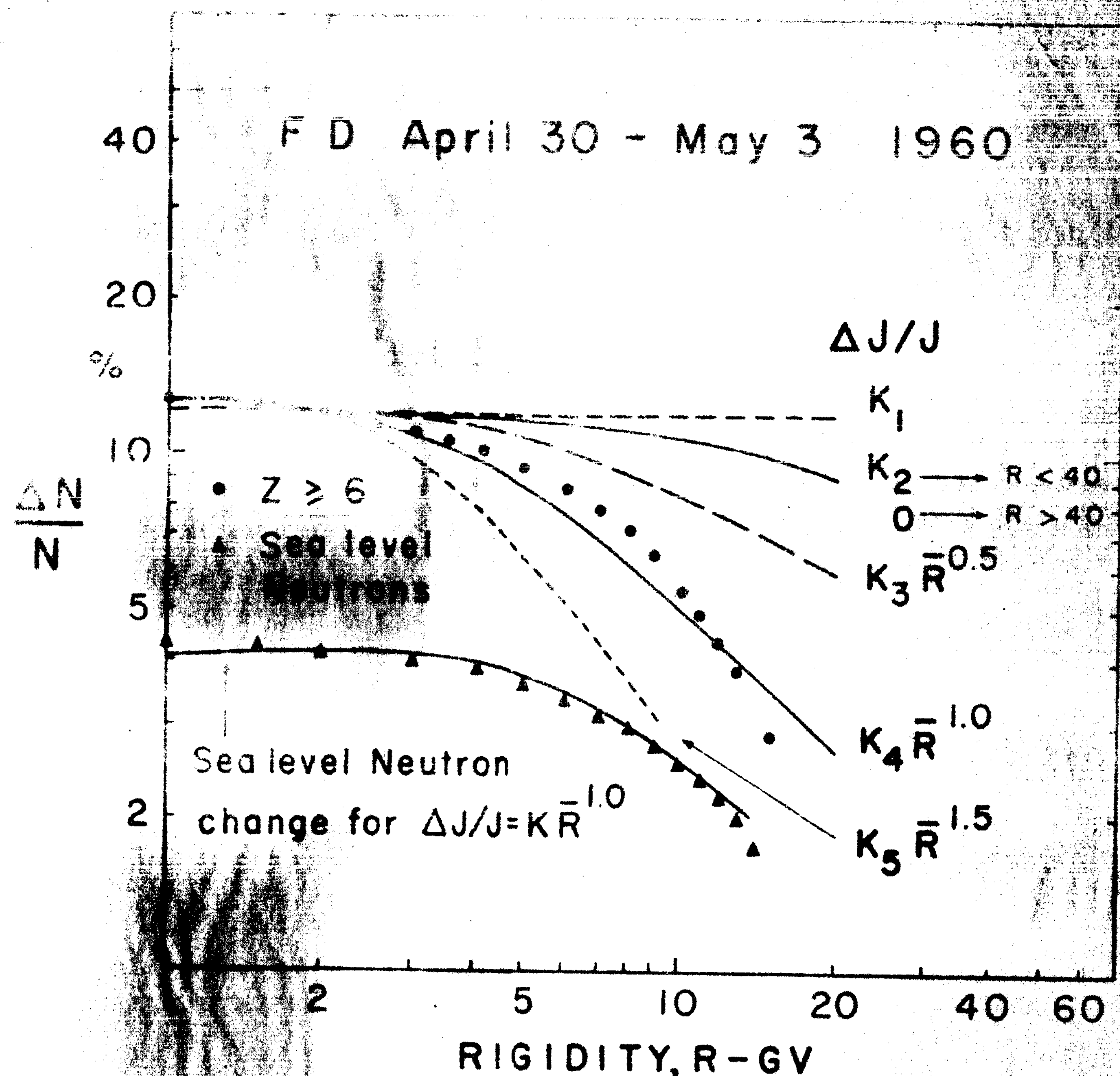
Fig. 8

Corresponding values of R_0 and K are also shown. In Fig. 7, the percentage change in the heavy nucleus flux is plotted as a function of geomagnetic cut-off rigidity. The percentage changes in the integral intensity, based upon various differential variation spectra, are also shown. The Explorer VII measurements satisfy the differential relationship $\delta J/J = KR^{-1.0}$, i.e. the differential change in intensity is inversely proportional to the rigidity.

In order to compare the above results with the data from neutron monitors, the integral intensity change was deduced from data recorded at a number of stations, and a smooth curve was plotted. The points represented as triangles were obtained in this manner. The solid line passing through these points represents the expected change in neutron monitor intensity resulting from a differential variation spectrum of the type $\delta J/J = KR^{-1.0}$. Thus, the differential change in the spectrum was the same for heavy nuclei and for protons.

IV. SOLAR PARTICLE EVENTS

A number of analyses relating to the possible arrival of solar-produced heavy nuclei were conducted. Ground-based instruments detected the arrival of solar particles on five occasions during the lifetime of the Explorer VII heavy nucleus experiment. The first, 4 May, 1960, was very short-lived, and, unfortunately, no heavy nucleus data


F D April 30 - May 3 1960
40
20
%
10
5
2
ΔN/N
ΔJ/J
K1
K2 → R < 40
0 → R > 40
K3 R^-0.5
K4 R^-1.0
K5 R^-1.5
• Z ≥ 6
▲ Sea level Neutrons
Sea level Neutron
change for ΔJ/J=K R^-1.0
2
5
10
20
40
60
RIGIDITY, R-GV

are available. The signal quality deteriorated considerably after 1 June, 1960. Nevertheless, the records were studied in detail in attempts to identify flux enhancements on 3 September, 12 November, 15 November and 20 November, 1960.

Only two flares, the outstanding events during November, 1960, produced heavy particle fluxes of a magnitude sufficient for detailed study. However, enhanced fluxes of heavy nuclei were observed on other occasions during the useful lifetime of the experiment.

A. <u>November 1960 Events</u>

Although the telemetry signals had deteriorated to an extent such that routine reduction was not feasible, it was possible to extract significant data from six passes during the flare events of 12 November and 15 November, 1960. These are summarized in Table 4.

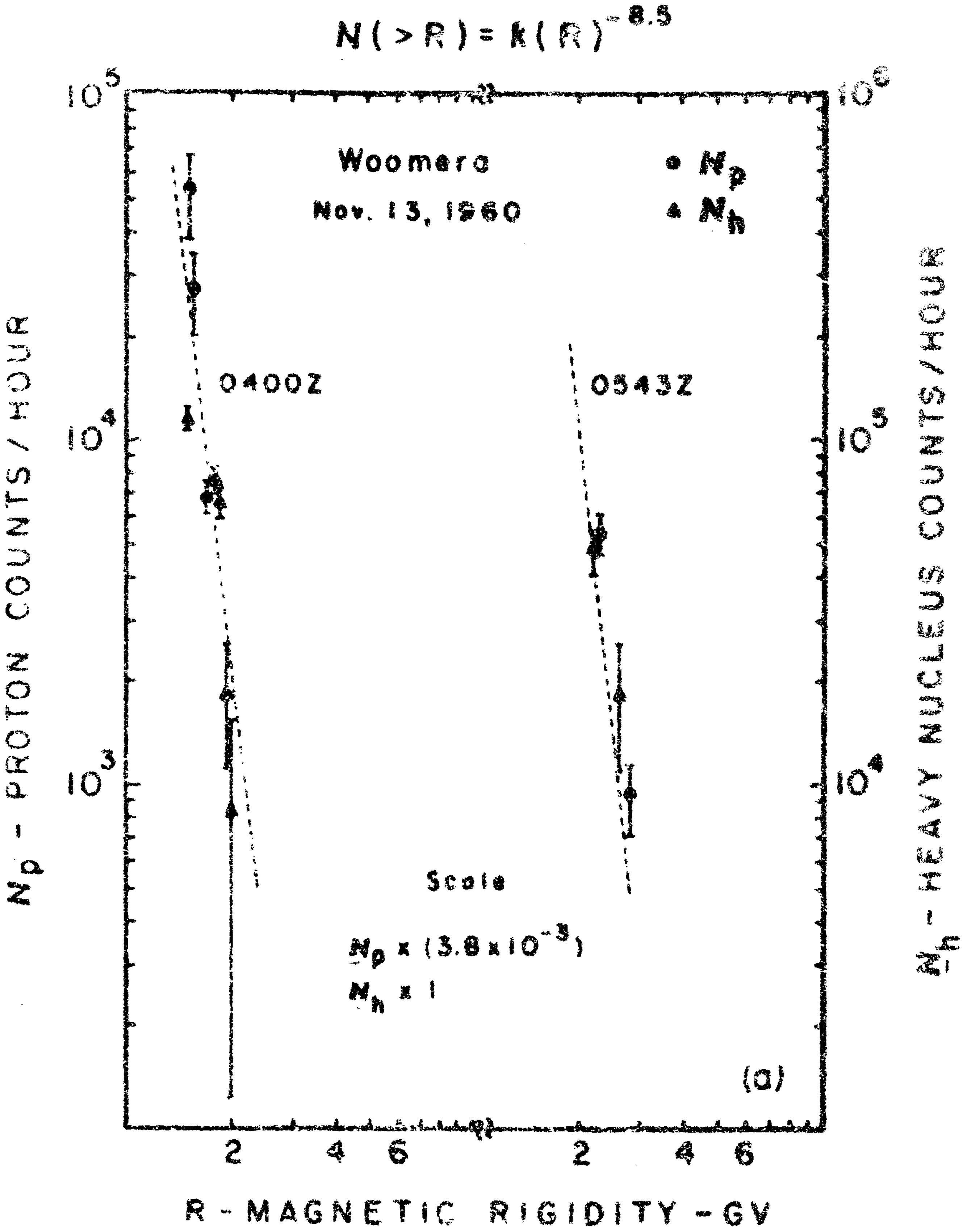
1. Magnetic Rigidity Spectrum

In Fig. 8, the counting rates attributable to solar-produced heavy nuclei are plotted as a function of threshold magnetic rigidity. The corresponding counting rates of the SUI 112 Geiger tube, recorded simultaneously on the same tapes, are also shown. Only enhancements which significantly exceeded the background rate have been included, since appreciable fluctuation in the galactic intensity reaching the earth were also occurring during this period.

TABLE 4

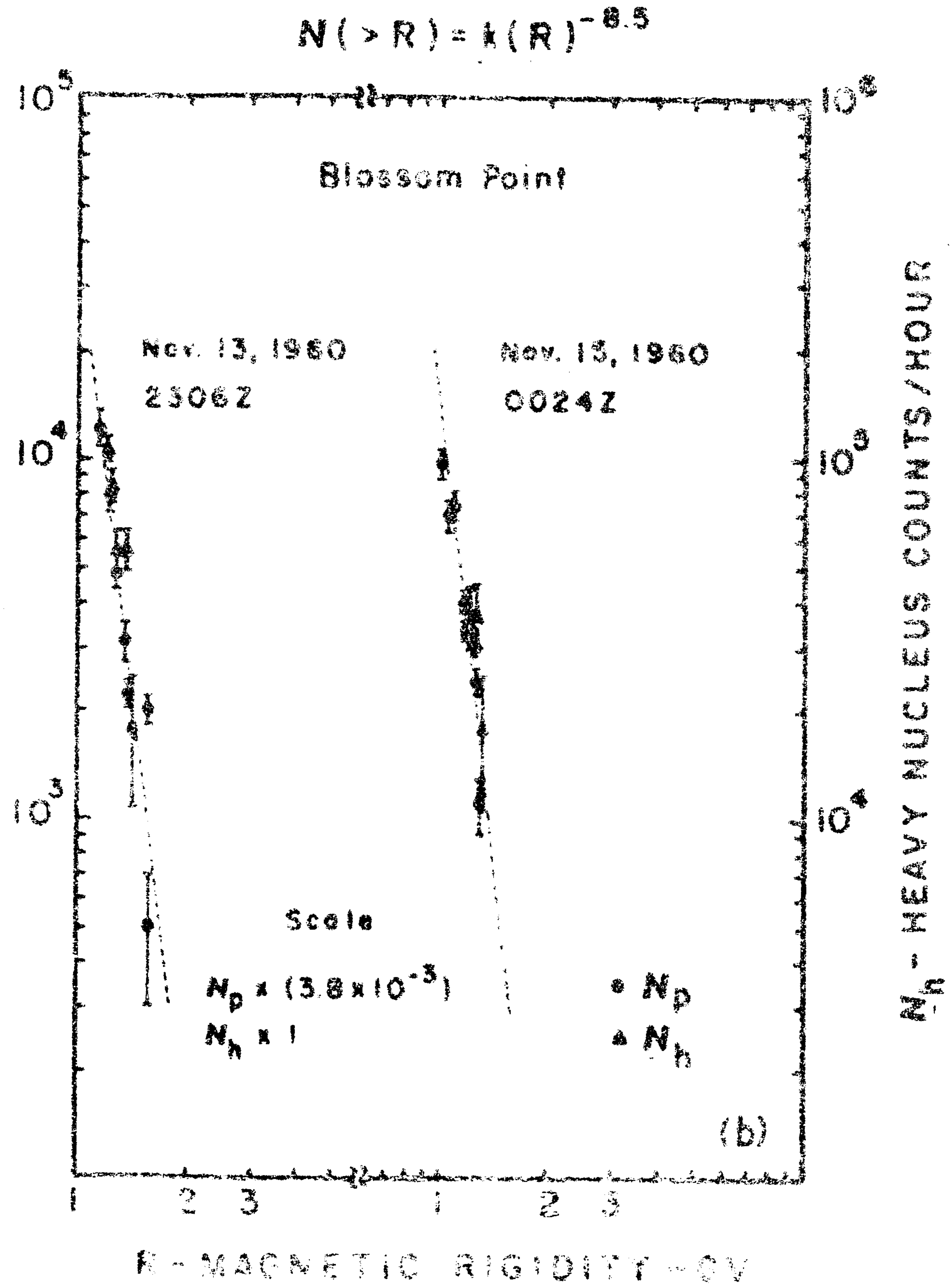
Passes during which solar-produced heavy nuclei were observed by Explorer VII.

Tracking Station	Time of Observation Time (UT)	Date	Geographic latitude interval
1) Woomera	0400	Nov. 13	$38^{\circ} - 42^{\circ}$
2) Woomera	0543	Nov. 13	$36^{\circ} - 38^{\circ}$
3) Blossom Point	2306	Nov. 13	$41^{\circ} - 43^{\circ}$
4) Blossom Point	0024	Nov. 15	$42^{\circ} - 44^{\circ}$
5) Blossom Point	2338	Nov. 16	$42^{\circ} - 45^{\circ}$
6) Blossom Point	2314	Nov. 17	$44^{\circ} - 48^{\circ}$



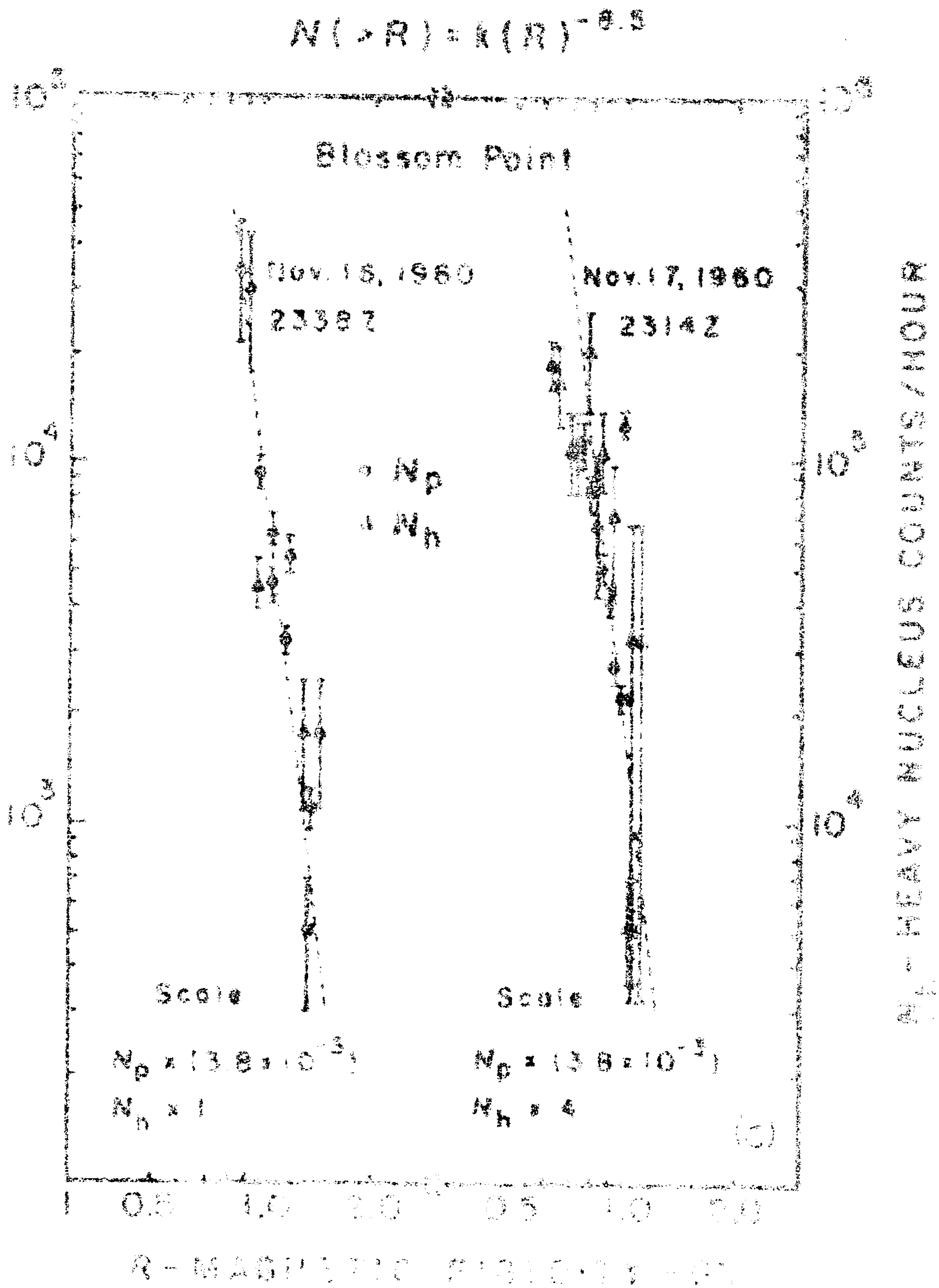
$N(>R) = k(R)^{-8.5}$
Woomera
Nov. 13, 1960
● N_p
▲ N_h
0400Z
0543Z
Scale
$N_p \times (3.8 \times 10^{-3})$
$N_h \times 1$
(a)
10^5
10^4
10^3
10^6
10^5
10^4
2
4
6
2
4
6
N_p - PROTON COUNTS / HOUR
N_h - HEAVY NUCLEUS COUNTS / HOUR
R - MAGNETIC RIGIDITY - GV

Fig. 8 a.



$N(>R) = k(R)^{-8.5}$
Blossom Point
Nov. 13, 1960
2306Z
Nov. 13, 1960
0024Z
Scale
$N_p \times (3.8 \times 10^{-3})$
$N_h \times 1$
• N_p
▲ N_h
(b)
10^5
10^4
10^3
N_h - HEAVY NUCLEUS COUNTS/HOUR
R - MAGNETIC RIGIDITY - GV

Fig. 8 b.



N(>R) = k(R)^-8.5
Blossom Point
Nov. 15, 1960
23387
Nov. 17, 1960
23142
Np
Nh
Scale
Np x (3.8 x 10^-3)
Nh x 1
Scale
Np x (3.8 x 10^-3)
Nh x 4
(c)
HEAVY NUCLEUS COUNTS/HOUR

It is seen that the ratio of proton to heavy nucleus fluxes was independent of magnetic rigidity over the range covered by the measurements in each case. A single factor suffices for normalizing the heavy particle intensity to the proton intensity for the first five passes. However, in the sixth pass the normalization constant changes by a factor of 4.

The data are compatible with a constant value of the exponent $\gamma = 3.5$ in a power law representation of the integral magnetic rigidity spectrum.

2. Time Variations

Fig. 9 is a semilogarithmic plot of the counting rate of particles with rigidities exceeding 1.5 GV as a function of elapsed time. Neutron monitor data recorded at Deep River and Thule are also shown, the latter having been normalized to the earliest heavy nucleus point (0400Z, 13 November, 1960). The satellite points cannot be fitted by a single exponential, although, as is seen in Fig. 10, they are consistent with a power law decay, and appear to follow the trend exhibited by the ground stations near the end of the event. Data following the 15 November injection also fall in line. It should be emphasized that the normalization between ground and satellite observations was made only with respect to the first heavy nucleus point at the left of the figure.

Fig. 11 shows the intensity variations following the 15 November event. In both cases, the decay follows a $T^{-3.1}$ law.

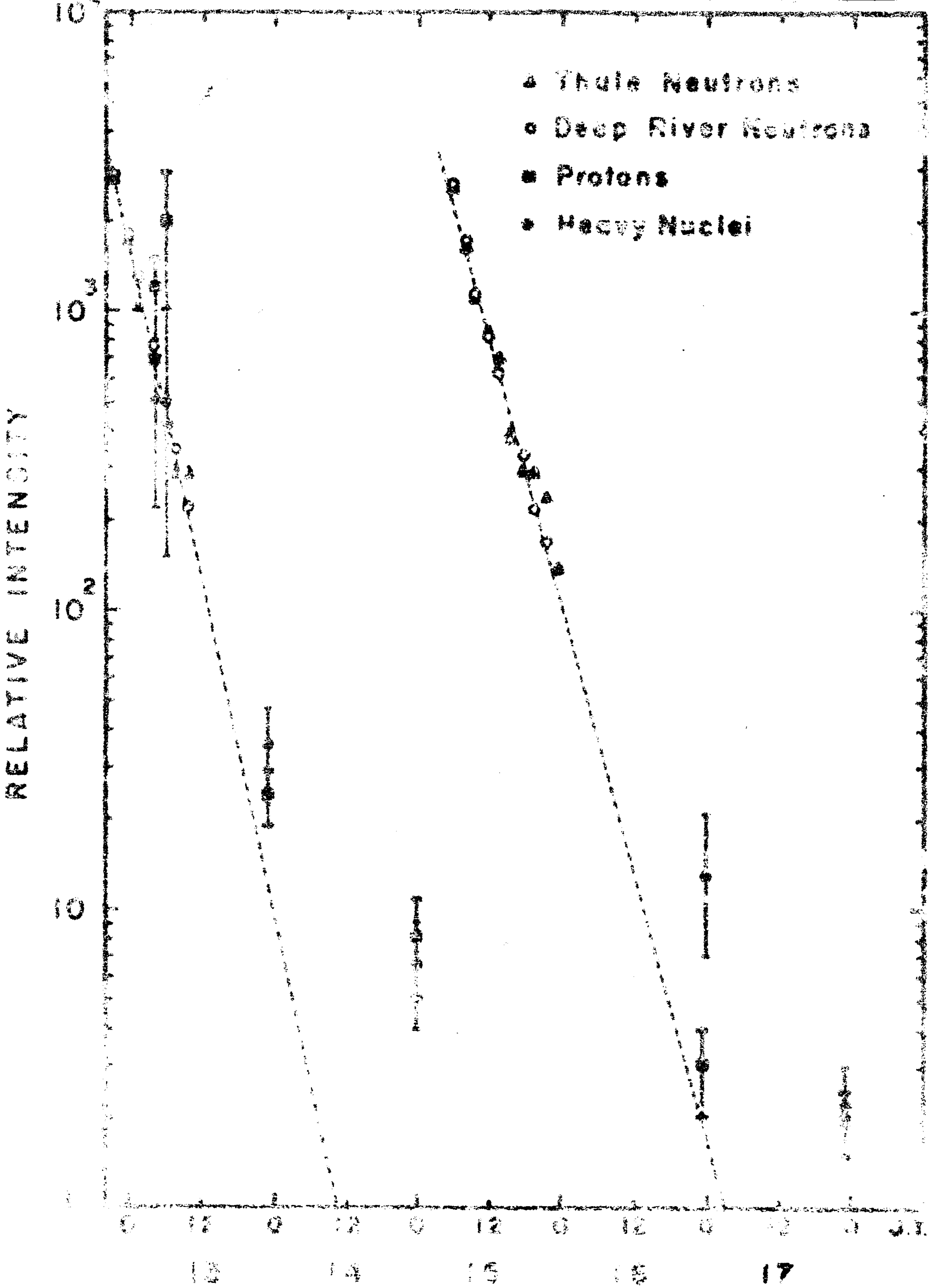


Fig. 9 November, 1960

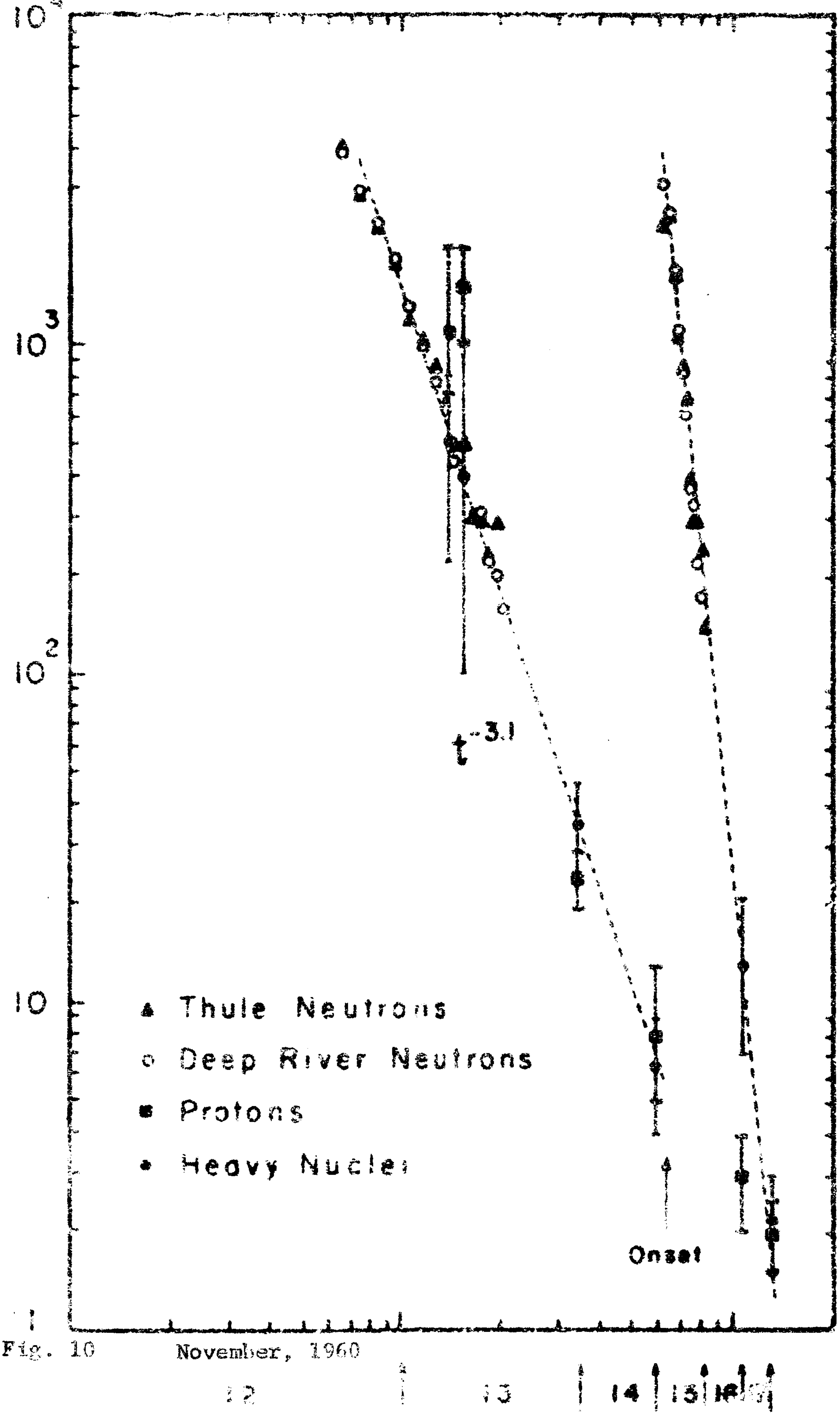


Fig. 10 November, 1960

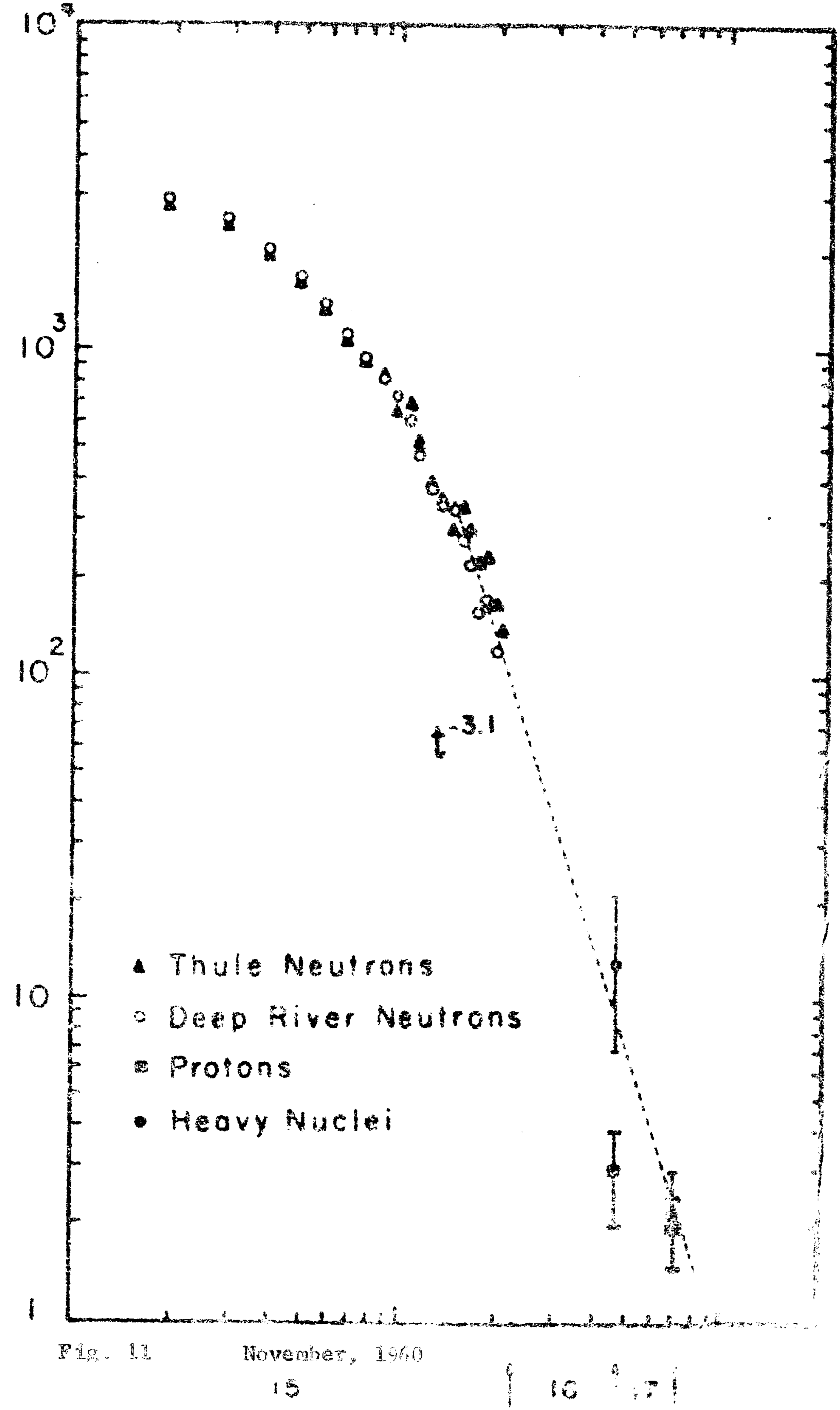


Fig. 11 November, 1960

B. Correlation With Solar Flares

Although only during November, 1960, were $Z \geq 6$ nuclei emitted with sufficient intensity to be detectable in individual passes, the possibility that recognizable flux enhancement might have occurred in association with other solar flares during the useful lifetime of the experiment was pursued further. For this purpose, a statistical study was carried out.

A total of seventy-eight solar flares of Importance 2 or greater occurred during the period for which reduced data were available. In each case, all data collected at high latitudes, corresponding to a threshold rigidity below 3 GV, were examined. The cards were sorted into two groups, based upon the onset time of the flare, one representing pre-flare conditions, the other comprising an interval up to approximately three hours following onset. Of the seventy-eight flares, statistically significant data in both groups were available in thirty-eight cases. The heavy nucleus flux in the second group, i.e. within three hours following the time of flare onset, was about 11% higher than the pre-flare group. This is regarded as a significant result, since the difference exceeds the 4σ level.

A similar analysis was conducted for individual solar flares of Importance ≥ 3. In this study, the cards were sorted into six groups, three of which corresponded to intervals of a few hours before onset, and the other three groups referred to periods after onset. A total of nine solar flares were studied in this manner, and although some flux enhancements were indicated, none reached the 3σ level. However, it should be noted that in view of the short duration of the time intervals, an increase of about 30% would correspond to the 3σ level. Furthermore, for the purpose of this analysis, the spectral parameters, rather than the intensity of particles with rigidities below 3 GV, were considered, thereby considerably diluting any effect which might have occurred.

The data were consequently analyzed in terms of rigidities below 3 GV alone. It was necessary to adjust the time intervals of the groups before and after the onset of the flare in order to attain reasonable statistics. The results were as follows:

1. 28 November 1959, Imp 3, duration 76 minutes, location N 10° E 30°

   An increase of 22% ($\approx 3\sigma$) occurred in the interval 0150 - 0678 U.T., 29 November. The duration of the optical flare was from 2010 to 2126 U.T. on 28 November.

2. 30 November 1959, Imp 3, duration 106 minutes, location N 07° E 07°

   No significant increase in heavy particle intensity occurred.

3. 7 January 1960, Imp 3, Duration > 38 minutes, location N 07° W 78°

No significant increase in heavy particle intensity occurred.

4. 11 January 1960, Imp 3, duration > 195 minutes, location N 23° E 03°

No heavy nucleus data available following onset.

5. 22 February 1960, Imp 3, duration > 13 minutes, location N 11° E 41°

No significant increase in heavy particle intensity occurred.

6. 12 April 1960, Imp 3, duration 12 minutes, location N 15° E 22°

No heavy nucleus data available preceding onset.

7. 29 April 1960, Imp 3, duration > 450 minutes, location N 12° W 21°

No significant increase in heavy particle intensity occurred.

8. 6 May 1960, Imp 3^{+}, duration 376 minutes, location S 10° E 08°

This flare was located near the central meridian. A polar cap absorption event of two and one-half days duration was ascribed to it. The optical flare persisted for more than six hours from 1404 to 2020 U.T. The intensity of heavy nuc-clei with magnetic rigidities < 2.5 GV increased by about 24% during the period 1541 U.T. on May 6 to 1675 U.T. on May 7. Between 0167 - 1675 U.T. on May 7th, the increase exceeded 50%.

9. 9 May 1960, Imp 3^+, duration > 197 minutes, location S 10° E 55°

No significant increase in heavy particle intensity occurred.

C. <u>Polar Cap Absorption Events</u>

Fourteen PCA events have been listed by Bailey[2)] between the launch date of Explorer VII and the end of 1960. Among these, heavy nucleus data are not available for four events, whereas five others coincided with solar high energy particle events already discussed. The results for the remaining five PCA events are as follows:

1. 12 January 1960, Class VS - Associated flare Imp 3

It commenced at 0700 U.T. and the duration was one and one-half days. No significant increase in the flux of heavy nuclei was observed during this event.

2. 28 April 1960, Class VS - Associated flare Imp 3

No significant increase in heavy particle intensity occurred.

3) 29 April 1960, Class M - Associated flare Imp 2^+

No significant increase in heavy particle intensity occurred.

4) 6 May 1960, Class M- Associated flare Imp 3

Heavy nucleus data recorded during two and one-half days of this PCA event have been compared with those for similar periods both before and after the event. An increase of approximately ± 20% occurred during this event.

5) 13 May 1960, Class S - Associated flare Imp 3

The scanty heavy nucleus data available during this period revealed no significant increase.

V. DETERMINATION OF ISOCOSMS

In order to compare the heavy nucleus intensity measurements with the theoretical predictions relating to threshold rigidities,[1)] isocosms were derived from the quiet period data. On the basis of the spectrum which prevailed during the quiet period, the heavy nucleus intensity measurements were reduced to a common altitude of 800 km by an appropriate adjustment of the geomagnetic threshold. Intensity vs latitude curves along geographic meridia were then plotted, and these served as the basis for constructing an isocosm map.

The analysis revealed general agreement between the intensity of heavy nuclei and the threshold rigidities as computed according to the formulation of Quenby and Wenk. However, accurate determinations of the location of the cosmic-ray equator were not feasible owing to the unfavorable geographical distribution of the data. From a rather gross point of view, however, the results agree qualitatively with those obtained with neutron monitors in the lower atmosphere.[3)]

VI. SOLAR CYCLE MODULATION

The heavy nucleus detector aboard Explorer VII provided for the first time the opportunity for observing directly the nature of the solar cycle modulation of the primary cosmic ray intensity. Thus, the uncertainties which are introduced by the presence of the atmosphere in interpreting intensity variations recorded by ground-based instruments have been eliminated.

Satellite-borne proton counters are not well adapted for a study of this type for several reasons. In the first place, the background of trapped radiation as well as the contribution by albedo render it virtually impossible to distinguish primary cosmic rays, even at relatively low satellite altitudes. Furthermore, solar-produced protons appear to be relatively more prevalent than heavy nuclei emanating from the sun.

The variational differential spectrum was determined from a comparison of the Explorer VII heavy nucleus data with measurements obtained with a spherical Cerenkov counter aboard Ariel I by the Imperial College group.[4] For all practical purposes, the two sets of measurements were identical, both in terms of detector geometry, and the bias levels which were set to accept nuclei with $Z \geq 6$. The monthly mean intensity values at Thule increased by about 8% between the periods covered by the two sets of measurements, near the beginning of 1960 and in the middle of 1962, as is seen in Fig. 12.

The rigidity spectra at the two different phases of the solar cycle are shown in Fig. 13. In both cases, the data refer to "quiet" periods as defined in Section III. A. The upper dotted curve has the generally-accepted solar minimum slope, corresponding to a value of $\gamma = 1.5$ in the integral power law representation. The Explorer VII and Ariel data are also plotted as power laws. The latter is adequately represented by two straight lines, but, as has already been discussed in Section III. A., three lines are required to fit the data recorded near solar maximum. The Ariel spectrum has been normalized with respect to that of Explorer VII in such a manner that the integral flux at 12 GV is 5% higher in accordance with an estimate based upon the records of two equatorial neutron monitors near sea level.

Both of the spectra determined from the satellite observations become steeper at higher rigidities. Between the beginning of 1960 and the middle of 1962, the change in the integral exponent, γ, in the range 3.5 to

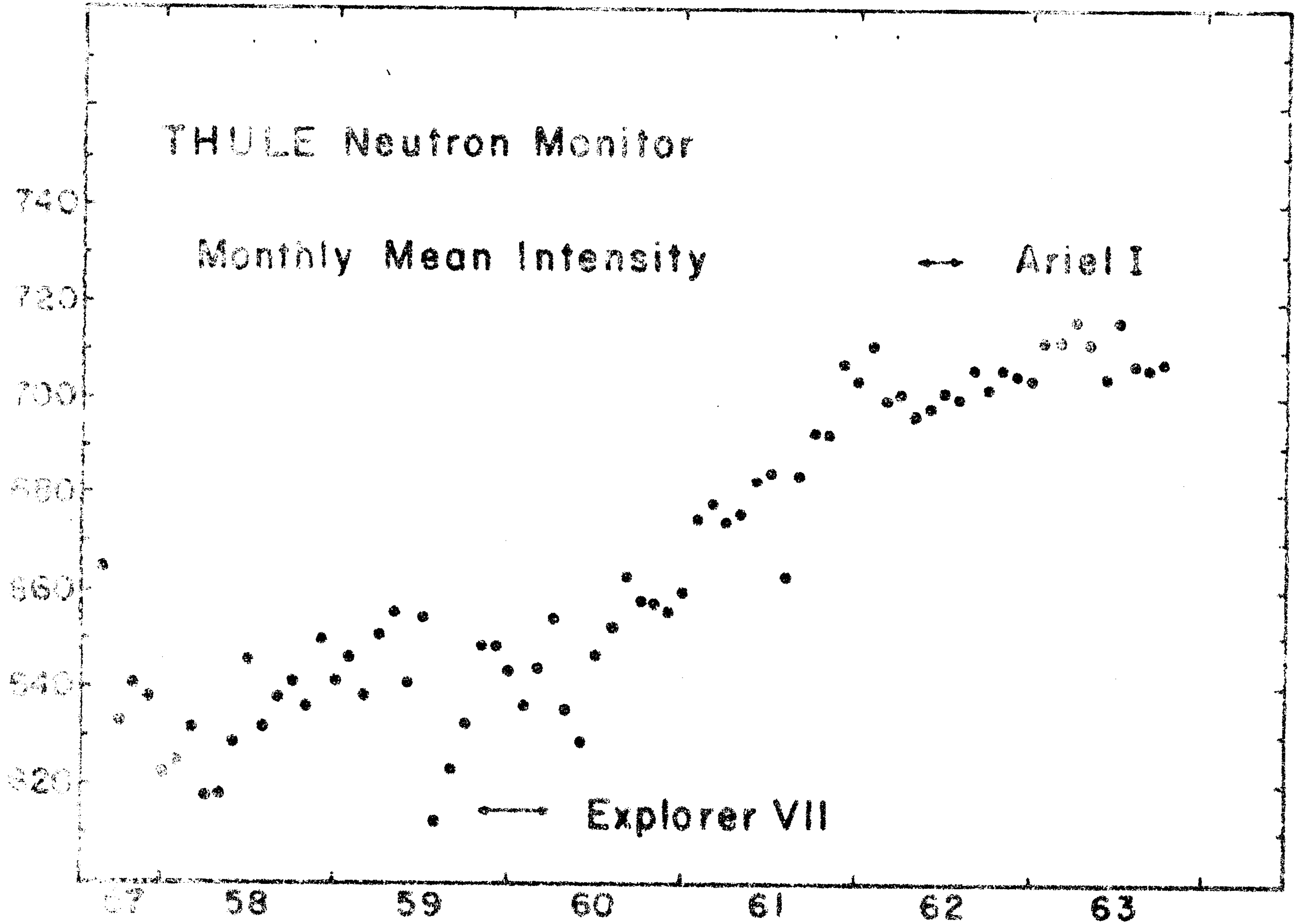
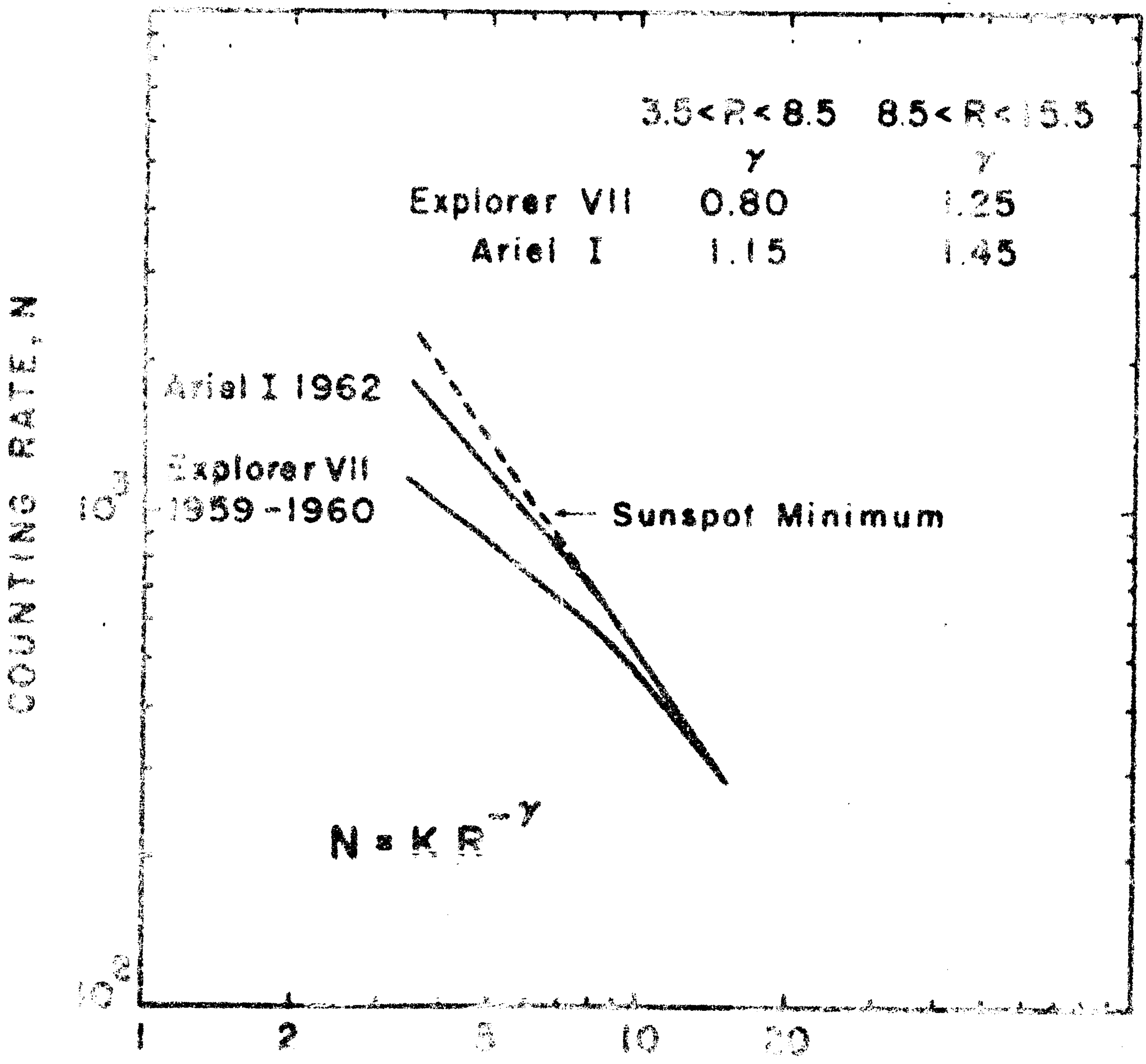

THULE Neutron Monitor
Monthly Mean Intensity
Ariel I
Explorer VII
740
720
700
680
660
640
620
57
58
59
60
61
62
63
YEAR

Figure 1[illegible]



3.5<R<8.5
8.5<R<15.5
γ
γ
Explorer VII
0.80
1.25
Ariel I
1.15
1.45
Ariel I 1962
Explorer VII
1959-1960
Sunspot Minimum
N = K R^{-γ}
COUNTING RATE, N
10^3
10^2
1
2
5
10
20

8.5 GV was 0.35, whereas the change from 1962 to solar minimum (based upon observations during the last solar cycle) was also 0.35. In the rigidity range 8.5 to 15.5 GV, the change in γ between the periods of Explorer VII and Ariel I was 0.20, whereas there was no change between the period of Ariel I and solar minimum.

The rigidity dependence of the percentage increase between the periods of Explorer VII and Ariel I is shown in Fig. 14. The result expected on the basis of a differential modulation of the form $\delta J/J = KR^{-1.0}$ is given by the solid line, whereas the dotted curve corresponds to a value of $\gamma = 1.5$. Both curves were normalized at 3 GV. It is clear that neither of these two lines fit the points representing the experimental observations, and no higher power would improve the situation.

However, an additional condition, i.e. the cessation of modulation at rigidities above a specified cutoff produces a considerable improvement. This is shown in Fig. 15. Here the predicted integral change was computed in terms of a differential variation spectrum $\delta J/J = KR^{-1.0}$ for $R < 20$ GV and $\delta J/J = 0$ for $R > 20$ GV. The same result is obtained if the comparison of the Explorer VII data is carried out with respect to the solar minimum spectrum instead of the spectrum determined by Ariel I.

On the basis of the aforementioned variational spectral law, the expected percentage increase which should have been registered by ground-based neutron monitors between 1960 and 1962 was calculated. The result,

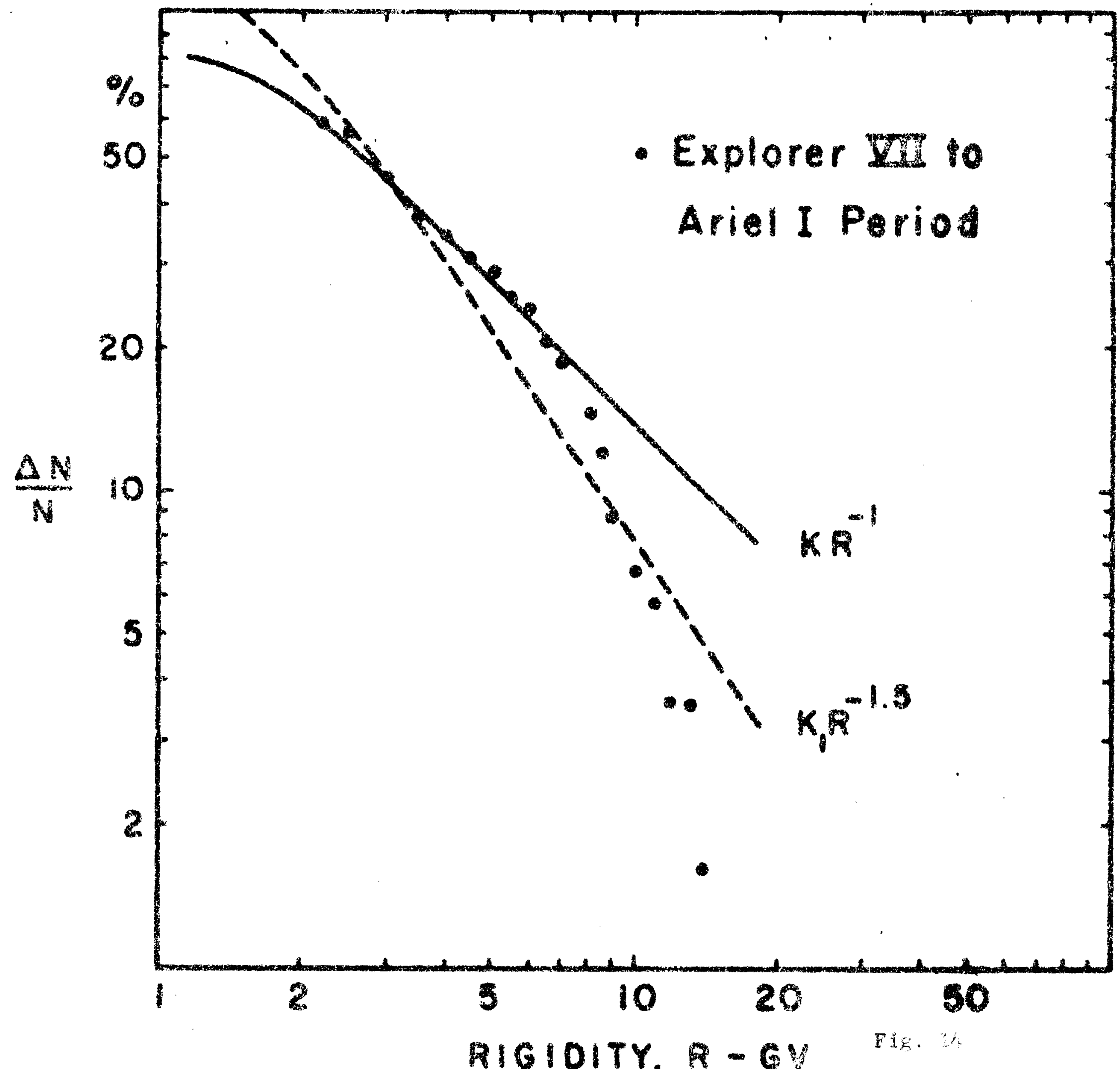
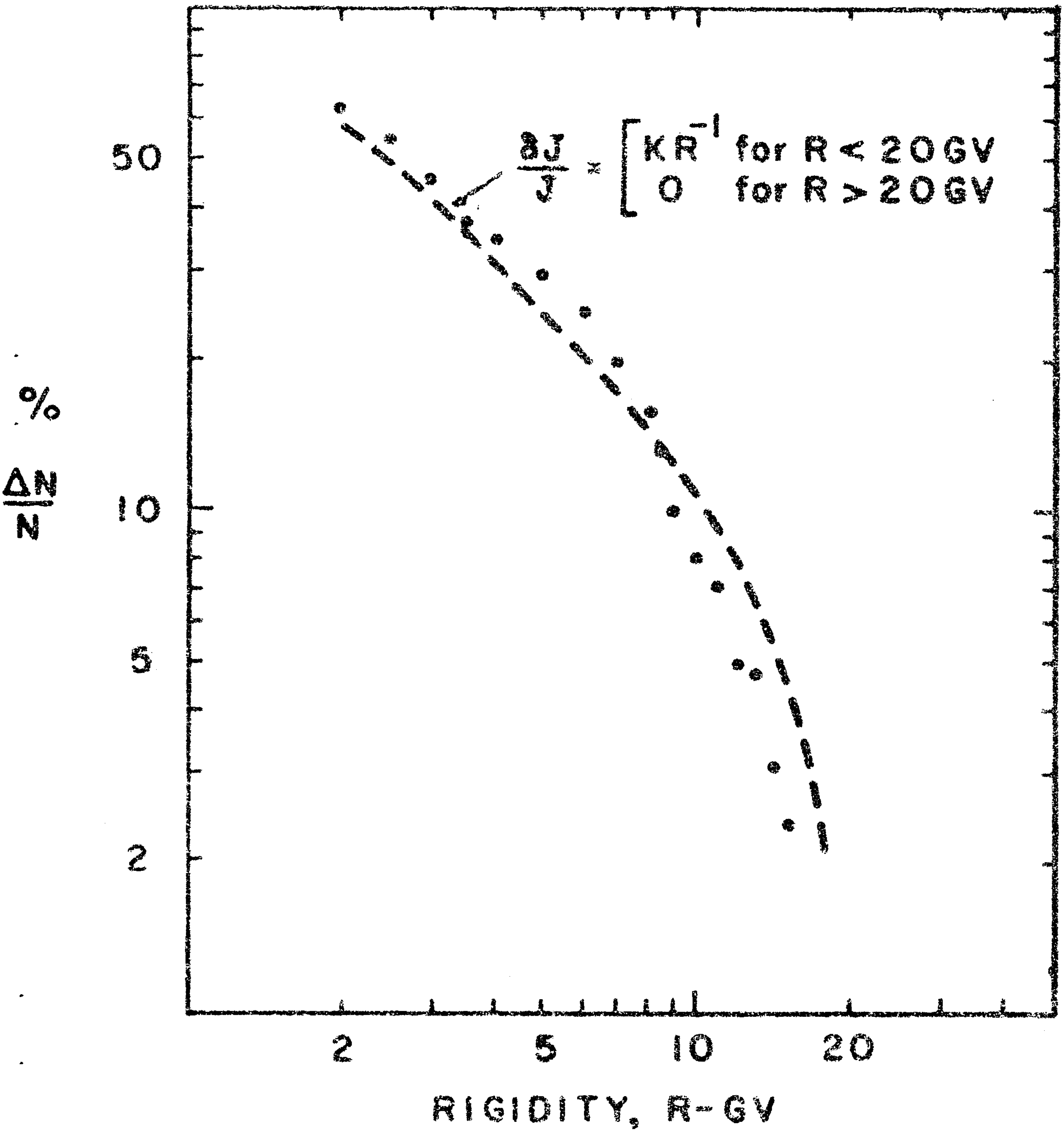

• Explorer VII to
Ariel I Period
KR^{-1}
$K_1R^{-1.5}$
%
50
20
10
5
2
$\frac{\Delta N}{N}$
1
2
5
10
20
50
RIGIDITY. R - GV

Fig. 14



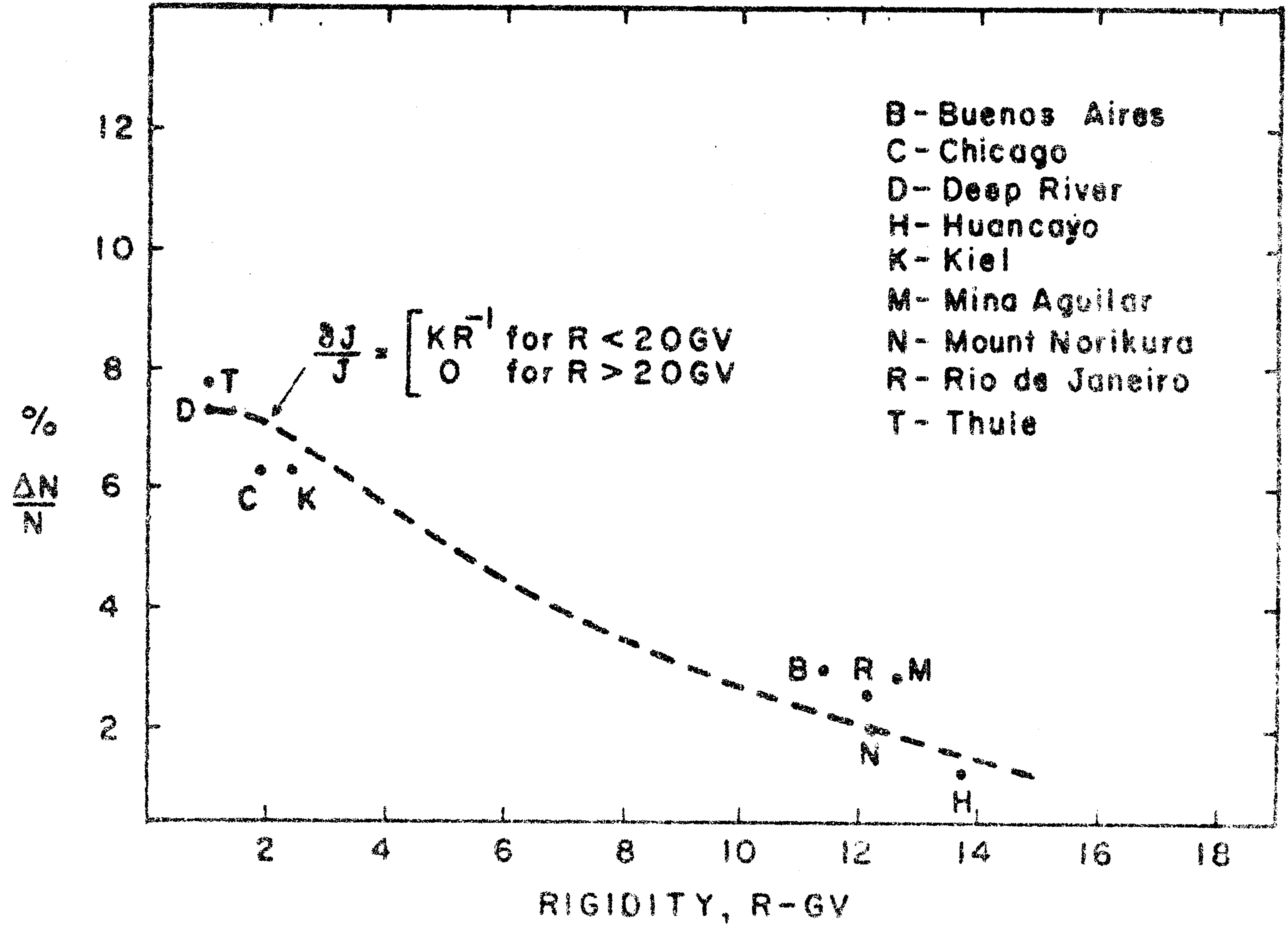
$\frac{\delta J}{J} = \begin{cases} KR^{-1} & \text{for } R < 20\,GV \\ 0 & \text{for } R > 20\,GV \end{cases}$
%
$\frac{\Delta N}{N}$
50
10
5
2
2
5
10
20
RIGIDITY, R-GV

Fig. 15

based upon atmospheric coupling coefficients given by Webber,[5] is shown by the dotted line in Fig. 16. The observations of nine neutron monitors are represented by the solid points. It is seen that, whereas stations at high latitudes recorded an increase of approximately 7 - 8% between the periods of Explorer VII and Ariel I, the increase at the equatorial stations amounted to only about 1%. The agreement between the dotted line, normalized to the intensity change observed at Deep River, and the other observations is satisfactory.

VII. CONCLUSIONS

Despite the limitations imposed by the lack of onboard storage and the availability of only a limited amount of real-time telemetry, significant results were obtained from the Explorer VII heavy nucleus experiment. In particular, heavy nuclei emitted by the sun were detected for the first time by a satellite-borne instrument. Significant details concerning the arrival of these particles at the earth, and their rigidity spectrum, were derived from a very limited amount of data. The spectrum of heavy nuclei near the maximum of solar activity over a rigidity interval from 1 GV to 15.5 GV was also obtained in an unambiguous manner for the first time. Furthermore, changes in the spectrum during periods of solar disturbance were revealed. Finally, the nature of the solar cycle modulation has, for the first time, been determined from measurements obtained with satellites. The differential modulation spectrum is of the



B - Buenos Aires
C - Chicago
D - Deep River
H - Huancayo
K - Kiel
M - Mina Aguilar
N - Mount Norikura
R - Rio de Janeiro
T - Thule
$\frac{\delta J}{J} = \begin{cases} KR^{-1} & \text{for } R < 20GV \\ 0 & \text{for } R > 20GV \end{cases}$
% $\frac{\Delta N}{N}$
RIGIDITY, R-GV

Fig. 16

form $\delta J/J = KR^{-1.0}$, for $R < R_c$ and $\delta J/J = 0$ for $R > R_c$, both for short-term fluctuations (Forbush decreases) and long term changes (solar-cycle modulation). The value of R_c changes during the solar cycle, and may be very much greater during the transient events than during the so-called "quiet" periods throughout the solar cycle.

The great expansion in the volume of data which could be achieved with onboard storage and an increase in the size of the detector would make it possible to study in considerably greater detail the nature of the modulation mechanisms. Although the simple pulse-ionization chamber may not be characterized by the degree of resolution which is, in principle, attainable with more complex detectors, the high counting rates of which it is capable represent a distinct advantage which has not been adequately exploited.

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